Detecting parity violation using trapped molecules

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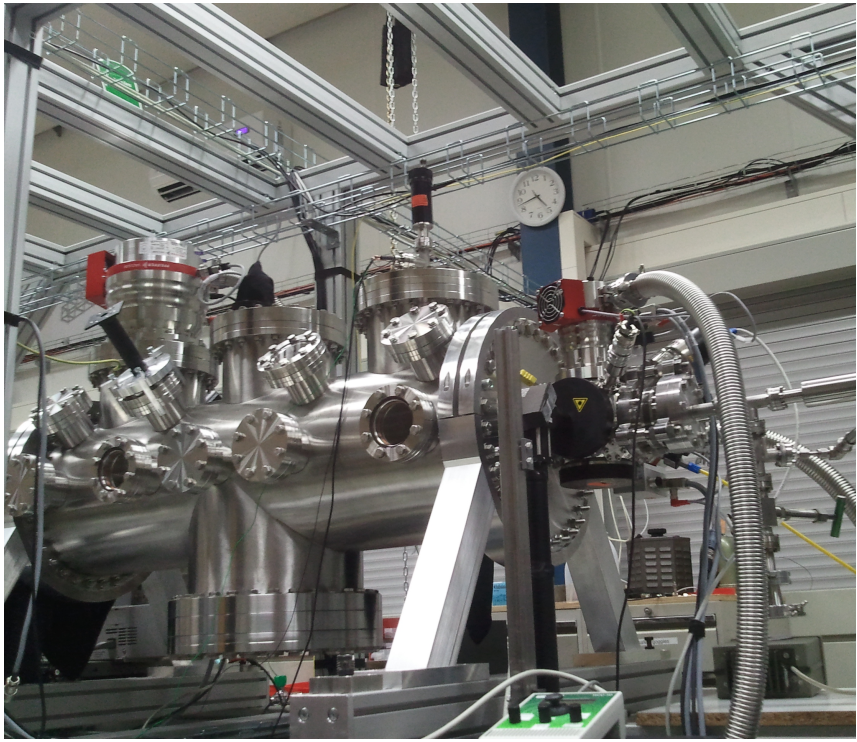
Kernfysisch Versneller Instituut

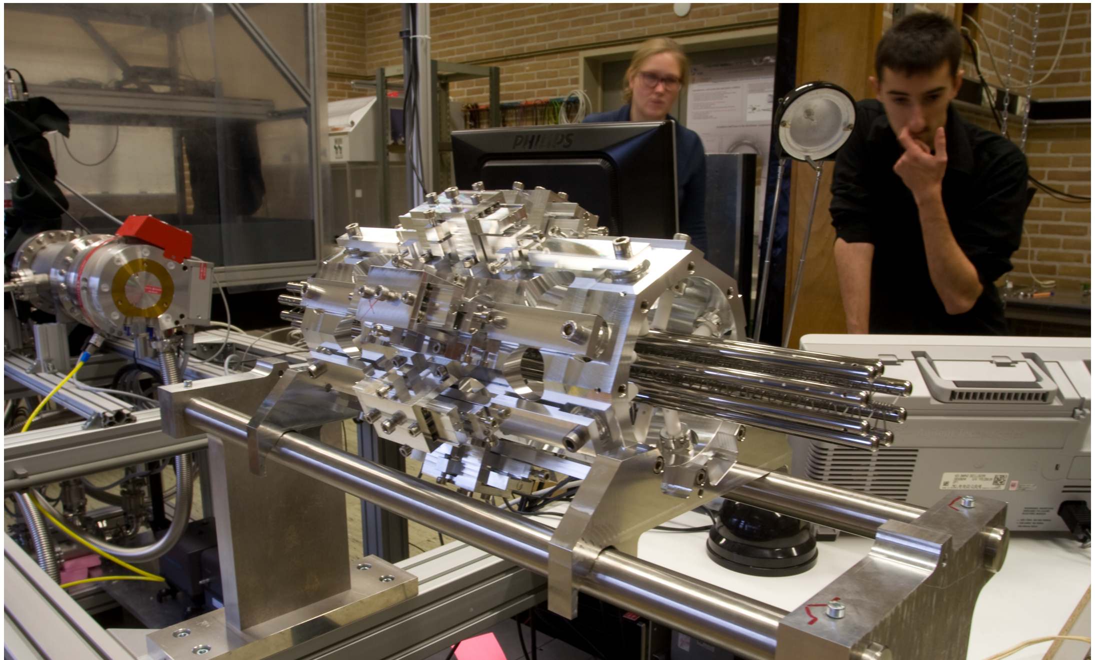
university of groningen

Outline

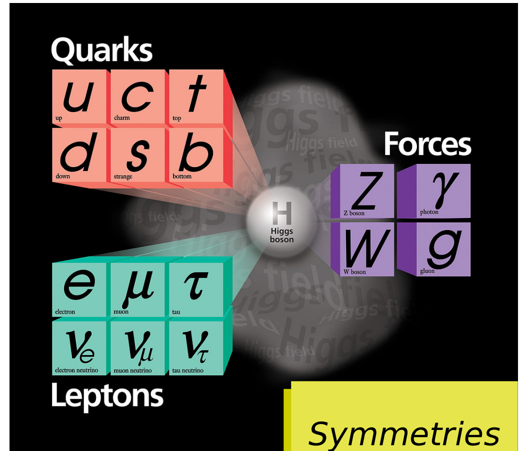
- Physics with cold molecules
- Ultracold ↔ precision
- Experimental setup

  Parity violation in SrF
- Current status and outlook





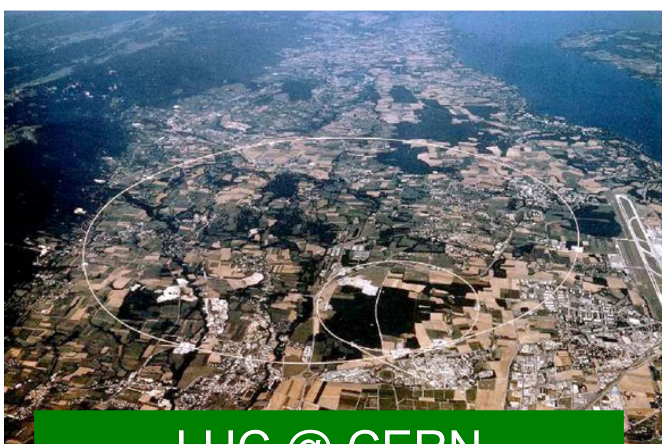
Tests of the Standard Model



Symmetries

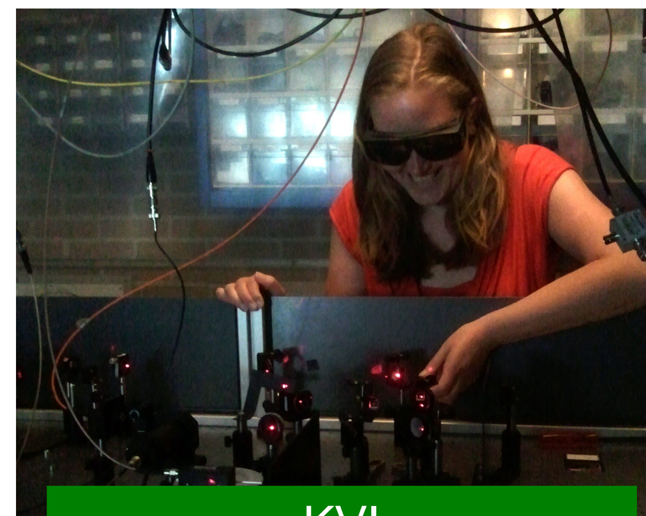
Precision measurements on the molecular scale

Direct observations of new particles at TeV scale



LHC @ CERN

Complementary



KVI

Example: detection of Higgs boson

Both constrain parameter space for SM extensions

Example: measurement of electron EDM in YbF *(Hinds, London)*

Cold molecules

- Combination of sensitivity and suitability to trap & cool
- Cooling → Longer coherence times
- Strong laser transitions: many photons/s

SrF, BaF, RaF, PbF	**NH_3**	**YbF**	**ThO, PbO, WC**	**Polar bi-alkali**
Parity violation	Time variation of μ	EDM	EDM	Dipole-dipole

… + many more

Cold molecules

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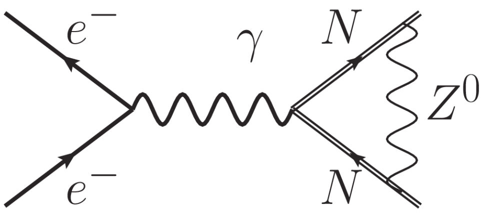
SrF, BaF, RaF, PbF	**NH_3, OH**	**YbF**	**ThO, PbO, WC**	**Polar bi-alkali**
Parity violation	Time variation of μ	EDM	EDM	Dipole-dipole
Stark deceleration Laser coolable Optical traps	Stark deceleration Fountain	Stark deceleration Laser cooling Fountain	Cryogenic beam	Optical traps

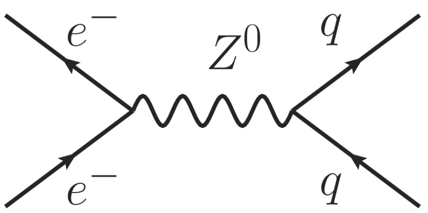
… + many more

Parity violation in diatomic molecules

- PV observed in atoms, never in molecules
- Enhanced by 10^5 in nearly degenerate rotational levels of opposite parity

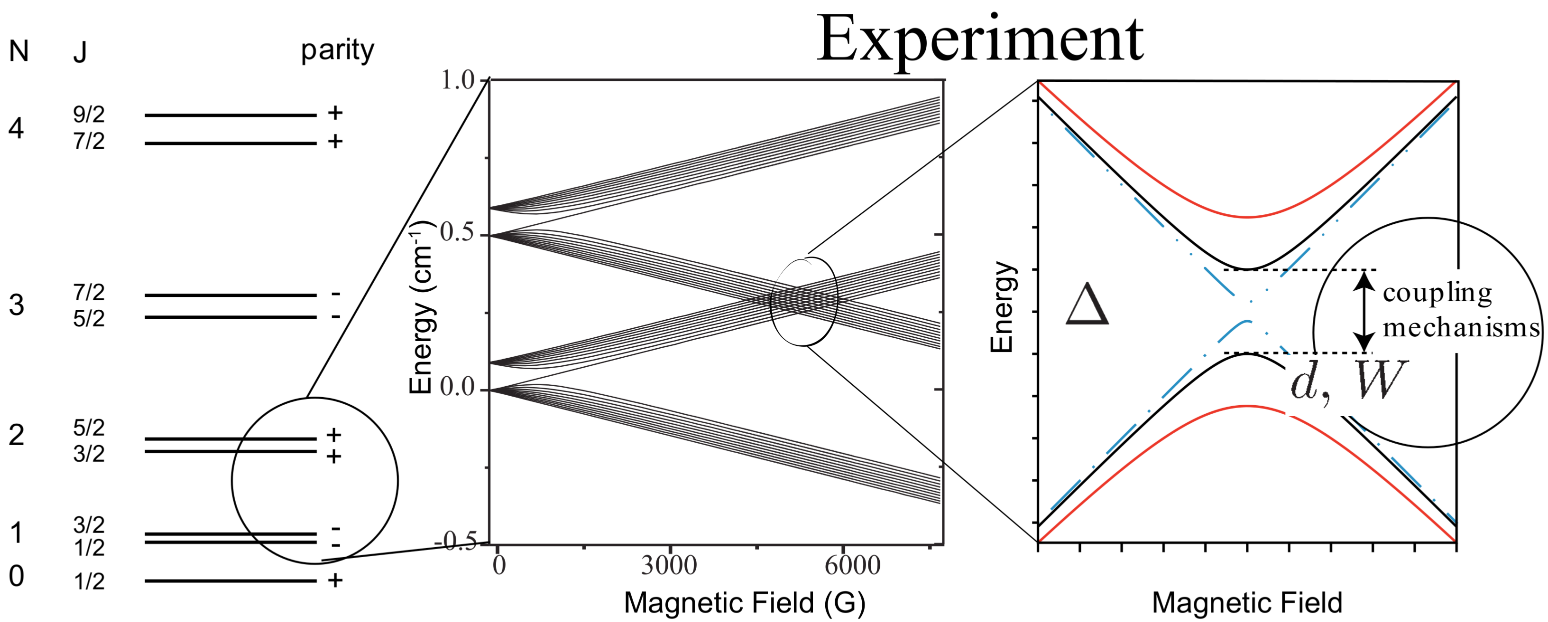
- Particularly good for NSD PV:
  - Anapole moment
  - Weak coupling constants $C_{2u,d}$;
- Sensitive to new physics at TeV scale
- Dark Matter Z-boson in PV observations (Marciano)





Review: M G Kozlov and L N Labzowsky 1995 J. Phys. B: At. Mol. Opt. Phys. 28 1933

PV measurement



$$E_0 \cos(\omega t)$$

Population signal

$$S = 4N \sin^2\left(\frac{\Delta T}{2}\right)\left[\underbrace{2\frac{W}{\Delta}\frac{dE_0}{\omega}}_{\text{P-odd}} + \underbrace{\left(\frac{dE_0}{\omega}\right)^2}_{\text{P-even}}\right]$$

Asymmetry

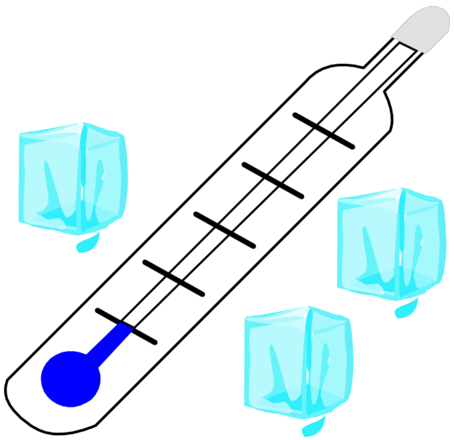
$$A = \frac{S(E_0) - S(-E_0)}{S(E_0) + S(-E_0)} = 2\frac{W}{\Delta}\frac{\omega}{dE_0}$$

$$\delta W \approx \frac{1}{2\sqrt{NT}}$$

DeMille et al., Phys. Rev. Lett. 100, 023003 (2008);
Kozlov et al., Sov. Phys. JETP, 1991, 73, 415-421

Ultracold ↔ precision

- Use molecular gas cloud isolated in vacuum
- Ultracold = standing still, lowest quantum state, colder than 1 mK
- No Doppler broadening
- Long coherence times
- Excellent control
- Well localized, good field homogeneity

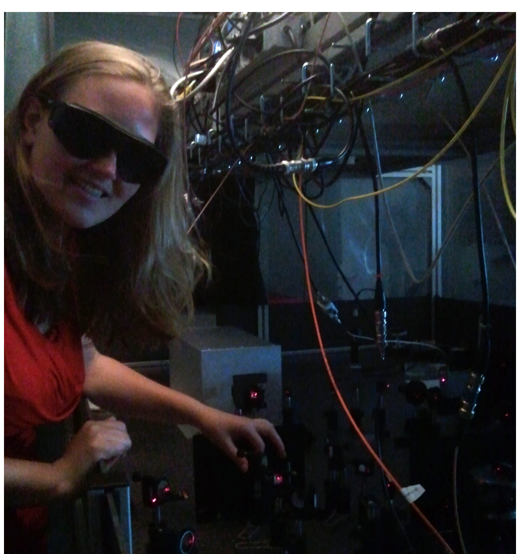


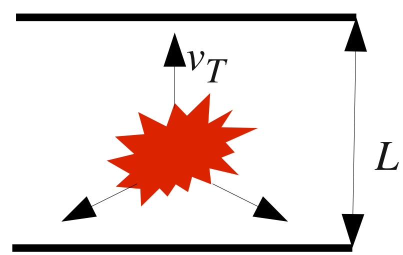
Ultracold ↔ precision

PV measurement sensitivity ~ $N^{1/2}\tau$, N=10^4/s

Increase τ and don't loose N: **slow things down**

	T (mK)	v_T (m/s)	L (mm)	τ (ms)
Beam 150 m/s	-	1.5	50	0.3
Decelerated and trapped	200	6	50	8
Laser cooled	0.15	0.15	50	300





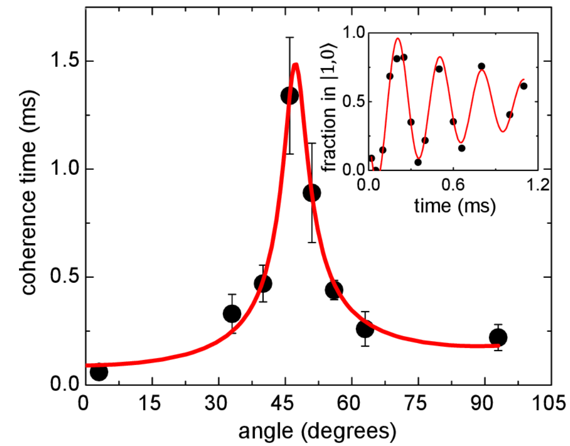
Expanding cloud of molecules inside measurement region

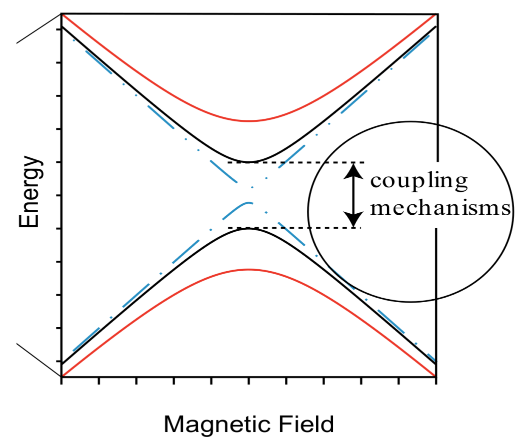
Percent-level measurement on NSD-PV in less than 1 week

(Cs ~15%)

Just trapped is not enough

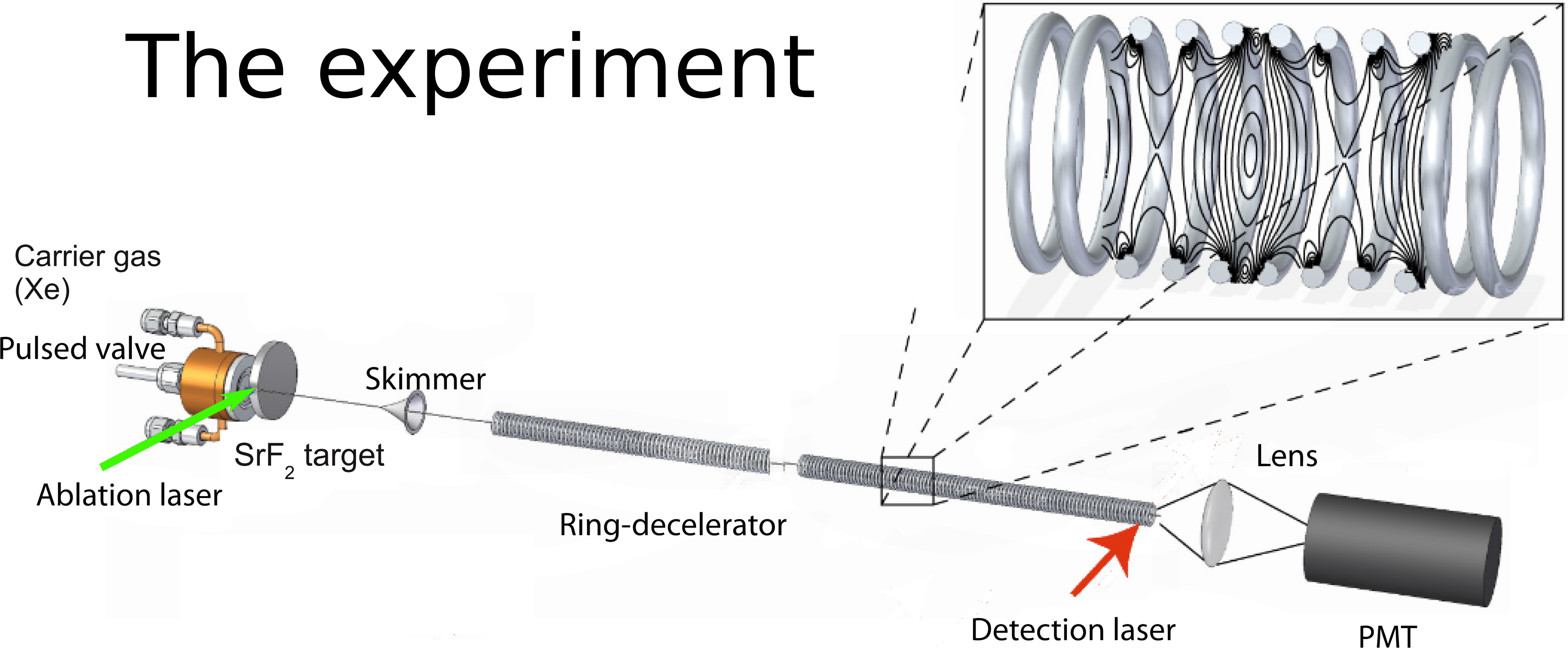
- Trapping time vs coherence time
  - Magic polarization angle, dipole trap
- External field stabilization
  - Small, permanent magnets
- Geometric phase shift
- Blackbody radiation
- Molecular interactions

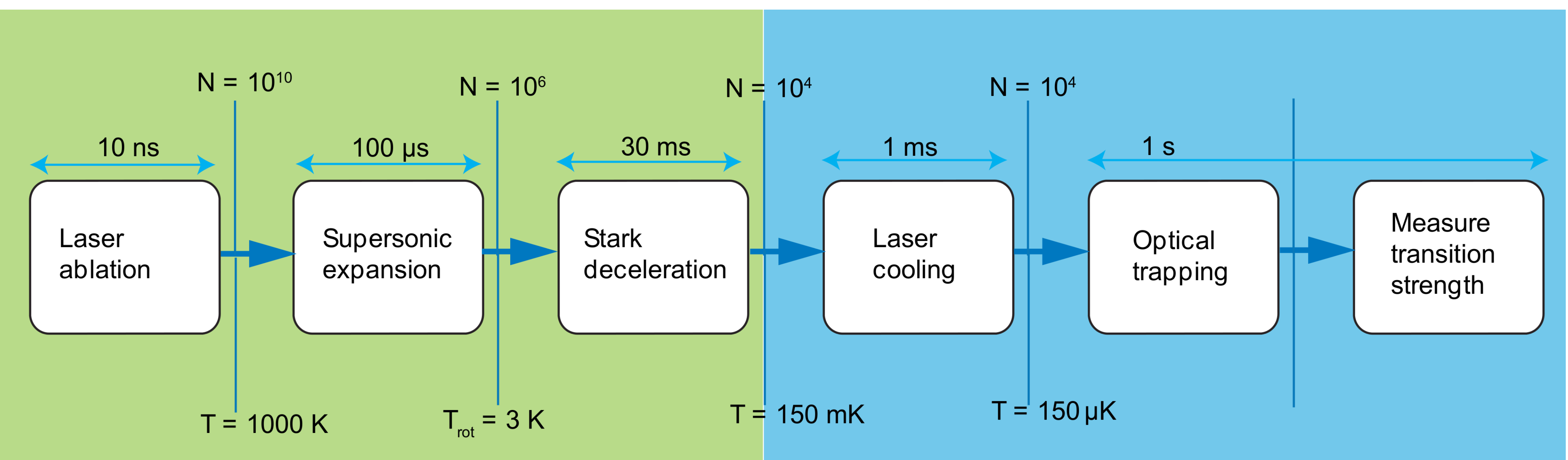




B. Neyenhuis et al., PRL 109 230403 (2012), B. Yan et al., arXiv:1305.5598

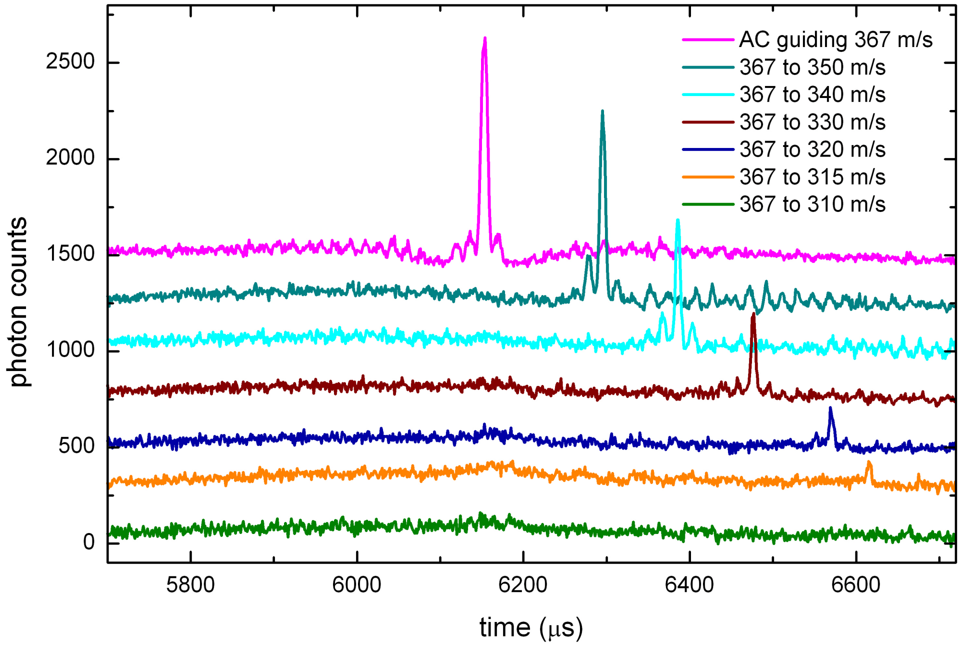
The experiment





Current results and status

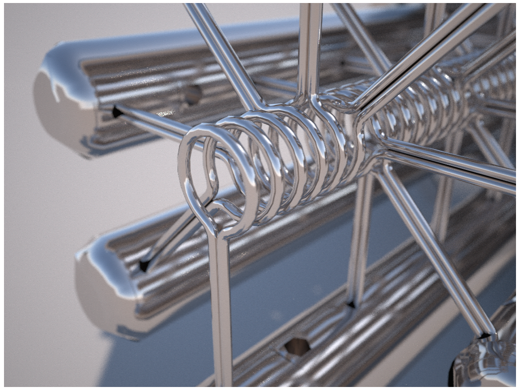
- Decelerated SrF
- Detection/cooling lasers:
  - Frequency stabilized
  - Sidebands created
- Trap design underway



2013:
Multipurpose ring-decelerator operational
Deceleration and trapping of SrF

Summary

- Diatomic molecules are sensitive probes for parity violation
- Precision measurements benefit from ultracold molecules
- We will combine Stark deceleration and laser cooling to achieve this
- First deceleration and trapping of SrF in 2013



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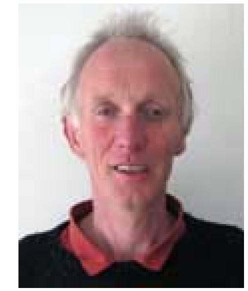
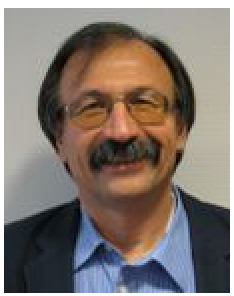
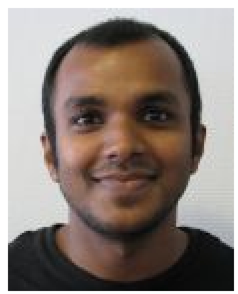


Leo Huisman



Klaus Jungmann



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